

# NASA Advisory Council

## October 6-7, 2010

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### Final Report of the Ad-Hoc Task Force on Planetary Defense

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# Task Force Members

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# Task Force Meetings Held

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April 15–16, 2010  
Cambridge, Massachusetts

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July 8–9, 2010  
Boulder, Colorado

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August 17 and 20, 2010  
Via Webex/Teleconference

# Introduction to TF Report

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- ▶ NASA's current search, track role for NEOs
- ▶ Executive and Congressional input on NASA role for Planetary Defense (PD)
- ▶ NASA has broad expertise in PD fields
  - NEO Science, Characterization, Deep Space Ops
- ▶ TF anticipates lead role for NASA in PD
- ▶ TF relied heavily on NRC report and other sources for background

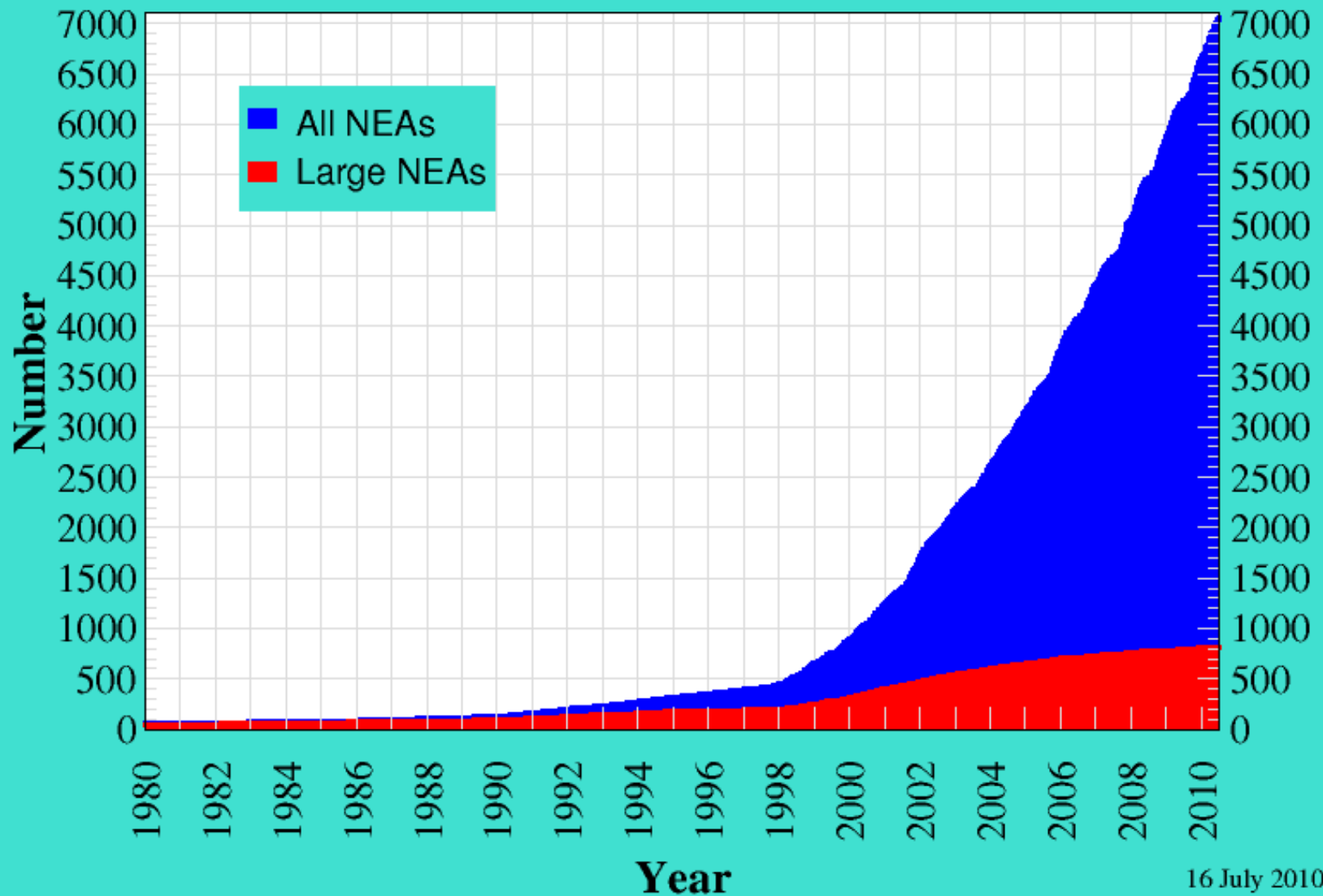
# NEO Hazard & Planetary Defense

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- ▶ NEO search programs are rapidly increasing discovery rate
- ▶ Many PHOs will have “worrisome probability of impact”
  - Threshold for concern? Impact probability of 1/1000? 1/100? 1/50?
- ▶ Imperfect information at time deflection decision needed
- ▶ Deflection decision frequency considerably higher than actual impact frequency (20:1, 50:1, 100:1 ?)
- ▶ International leadership needed: Inevitable risk shifting as impact point point is moved to eliminate risk for all

# Known Near-Earth Asteroids

1980-Jan through 2010-Jun



16 July 2010

Alan B. Chamberlin (JPL)

# Synergies from Planetary Defense

(1 of 2)

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- ▶ NASA NEO activity is “3-D” : exploration, science, planetary defense (PD)
  - Minor incremental cost to “other” space missions can yield large increase in PD knowledge
  - Example: Science mission can demonstrate prox ops algorithms for PD, human exploration
  - Example: NEO’s interior structure, physical properties, and stability of surface materials (for human exploration) aids PD planning



# Synergies from Planetary Defense

(2 of 2)

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- ▶ Time is a 4th dimension of NEO research
  - Early integration of PD results in faster maturity of technology
  - Eliminates cost of duplicate flight missions
- ▶ Integrating PD into science and human exploration missions increases overall knowledge return
  - Meets needs of managers, policy makers, scientists, public



# Recommendations

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1. Organize for Effective Action on Planetary Defense
2. Acquire Essential Search, Track, and Warning Capabilities
3. Investigate the Nature of the Impact Threat
4. Prepare to Respond to Impact Threats
5. Lead U.S. Planetary Defense Efforts in National and International Forums

# 1: Organize for Effective Action on Planetary Defense (1 of 5)

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**NASA should establish an organizational element to focus on the issues, activities and budget necessary for effective Planetary Defense planning; to acquire the required capabilities, to include development of identification and mitigation processes and technologies; and to prepare for leadership of the U.S. and international response to the impact hazard.**

# 1: Organize for Effective Action on Planetary Defense (2 of 5)

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## 1.1 Planetary Defense Coordination Office (PDCO)

- ▶ Officer responsible directly to the NASA Administrator
- ▶ Coordinate expertise and resources to establish a capability to detect NEO impact threat, plan and test measures to mitigate such a threat.
- ▶ Plan, submit , disburse budgets for PD program
- ▶ Coordinate and oversee all PD activities by MDs, centers, and agency projects
- ▶ U.S. government and international space agency and partner interfaces for PD
- ▶ NASA public awareness activities and any NEO impact public info release
- ▶ Small staff, support seconded from agency offices

# 1: Organize for Effective Action on Planetary Defense (3 of 5)

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## 1.2 PD Activities

- ▶ A near-term effort to accomplish the George E. Brown NEO Survey Act of 2005 (90% / 140m)
- ▶ Planetary radar support – observations to increase NEO orbit precision, reduce position error ellipse (\$)

# 1: Organize for Effective Action on Planetary Defense (4 of 5)

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## 1.3 PD Budget

- ▶ Long-term, continuous monitoring of the NEO population, characterization, PD demo missions
- ▶ \$250–\$300M annually for a decade
  - Not an expensive effort ( $\sim 1/60^{\text{th}}$  of NASA budget)
  - Drops to modest steady state: \$50–\$75M annually
- ▶ No standing “NEO deflection alert” system to maintain
  - With proper search/track and “complete” catalog, build and launch as necessary

# 1: Organize for Effective Action on Planetary Defense (5 of 5)

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## 1.4 Develop PD interfaces within/external to U.S. Government

- ▶ Short term impact response procedures with DHS, other emergency agencies
- ▶ International initiatives for joint PD demo missions
- ▶ NASA should challenge international community to join analytical, operational, and decision-making PD activities

## 2: Acquire Essential Search, Track, and Warning Capabilities (1 of 6)

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NASA should significantly improve the nation's discovery and tracking capabilities for early detection of potential NEO impactors, and for tracking them with the precision required for high confidence in potential impact assessments.



## 2: Acquire Essential Search, Track, and Warning Capabilities (2 of 6)

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### 2.1 NEO Search

The task force recommends that NASA immediately initiate a space-based infrared telescopic NEO search project as the primary means of meeting the George E. Brown Survey goal.

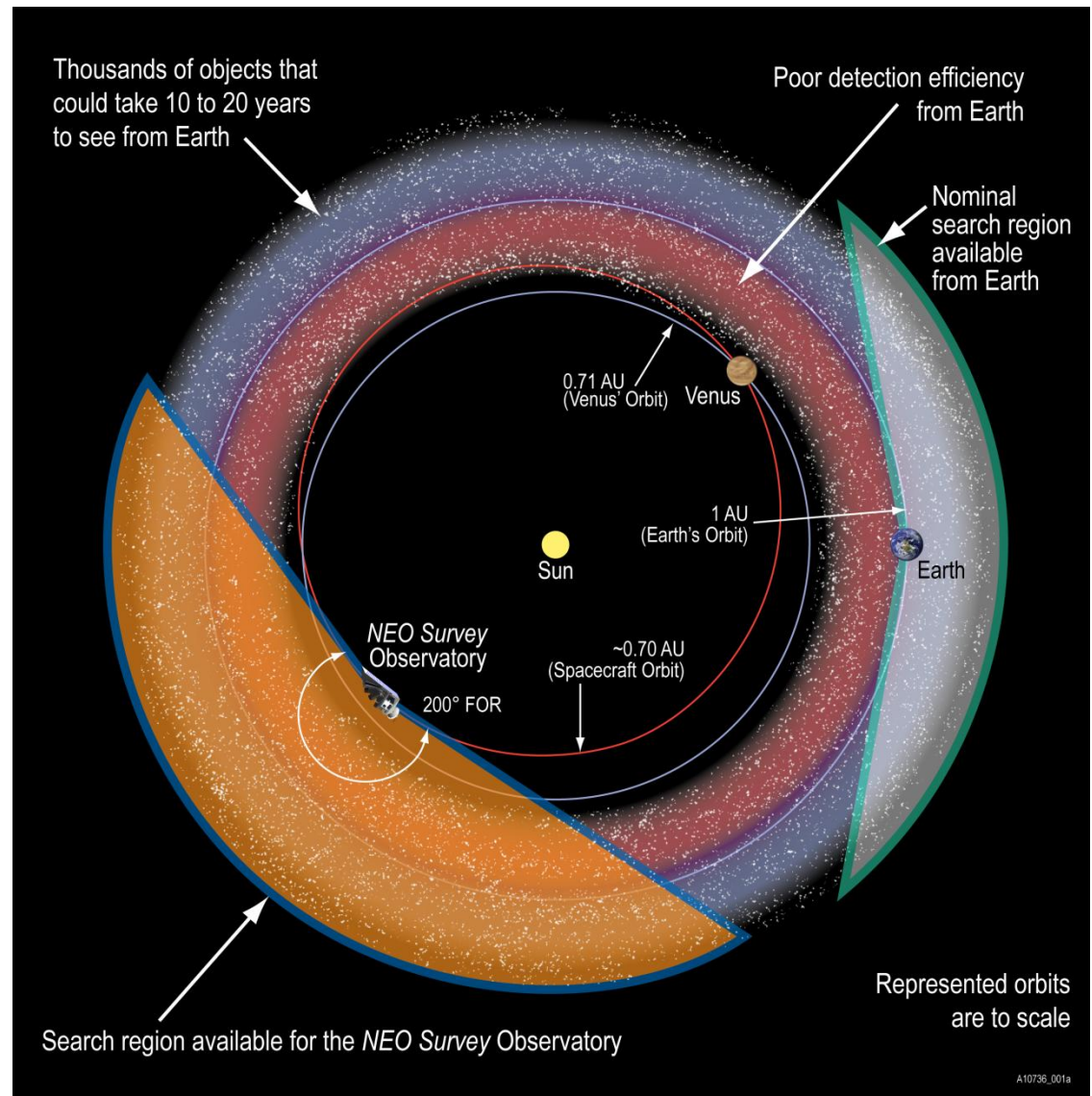
# 2: Acquire Essential Search, Track, and Warning Capabilities (3 of 6)

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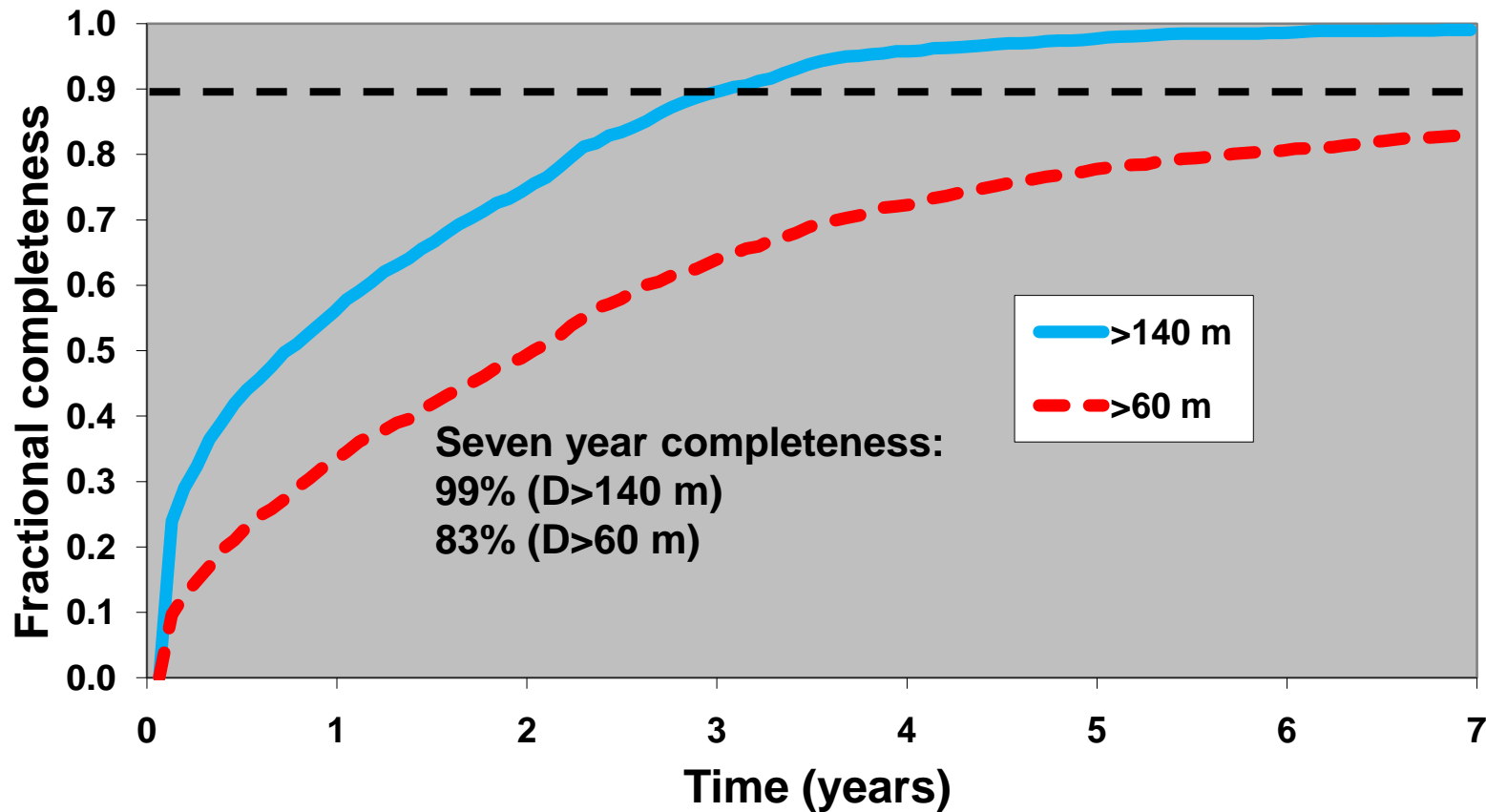
## 2.1 NEO Search (cont'd.)

- ▶ Deploy faster, efficient IR telescope while assisting ground-based facilities
- ▶ Meets survey goal in  $< 7$  yrs; enables follow-up orbit determination
- ▶ Observing frequency and geometry reduces need for deflection campaigns
- ▶ Mission cost balanced by avoided deflection/transponder launches
- ▶ Investigate cost/benefit of a pair of IR, Venus-like-orbit s/c
- ▶ Rapid ID of NEOs accessible for human exploration

Illustration of orbit geometry when Earth and the spacecraft are on opposite sides of the sun. Earth-based telescopes will detect some NEOs that the space-based telescope will miss during the NEO perihelion passage. The resulting completeness will be better than with any single telescope.

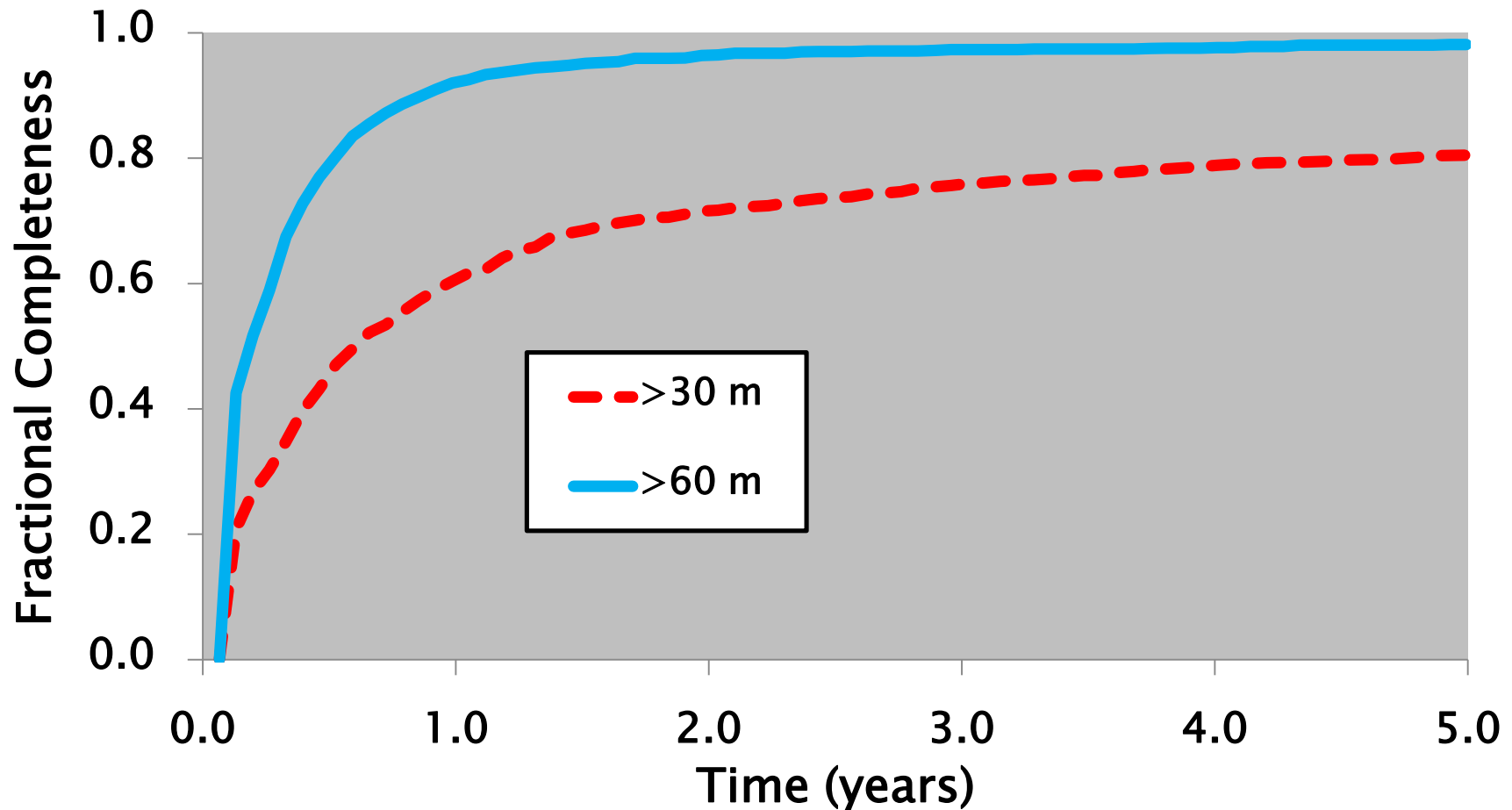


# Completeness for two oppositely-phased spacecraft with 50 cm IR telescopes for entire NEO population



Completeness plot when we have two IR telescopes in Venus-like orbit, with orbital phase  $180^\circ$  apart. This is for the entire NEO population (Earth defense application).

## Completeness for two oppositely-phased spacecraft with 50 cm IR telescopes for Human Exploration targets



Completeness plot when we have two IR telescopes in Venus-like orbit, with orbital phase  $180^\circ$  apart. This is for Human Exploration targets which can be reached with  $<5$  km/s one-way  $\Delta v$  (from Earth escape).

## 2: Acquire Essential Search, Track, and Warning Capabilities (4 of 6)

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### 2.2 Orbit Determination

NASA should plan and budget for the incremental costs of maintaining the Arecibo and Goldstone planetary radars.

- ▶ Facilitate rapid orbit refinement and detailed physical NEO characterization
- ▶ Provides definitive orbit precision for subset of NEOs observable
- ▶ Can determine binary NEOs, component masses, 3-D shape, rotation state (comparable to flyby missions for subset of NEOs)

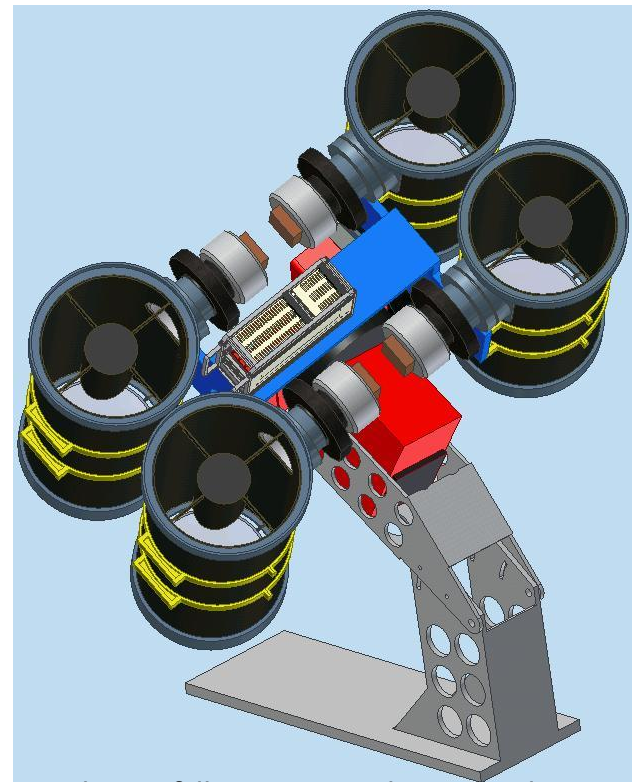


## 2: Acquire Essential Search, Track, and Warning Capabilities (5 of 6)

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### 2.3 Short-term Warning

NASA should investigate development of low cost, short-term impact warning systems



<http://fallingstar.com/danger.html>



# 2: Acquire Essential Search, Track, and Warning Capabilities (6 of 6)

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## 2.3 Short-term Warning (Cont'd)

- ▶ Provides days or weeks of impact warning for ~ 60% of these events
- ▶ Addresses, at low cost, gap in current search
- ▶ Aimed at most frequent impactors (20–30 m objects, avg. impact 50 yrs)
- ▶ \$1M–\$2M per telescope
- ▶ Encourage widespread deployment by international space agencies, amateur and academic astronomers
- ▶ Public education, student interest and involvement

### 3: Investigate the Nature of the Impact Threat (1 of 3)

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To guide development of effective impact mitigation techniques, NASA should acquire a better understanding of NEO characteristics by using existing and new science and exploration research capabilities, including ground-based observations, impact experiments, computer simulations, and *in situ* asteroid investigation.

# 3: Investigate the Nature of the Impact Threat (2 of 3)

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## 3.1 Physical Characteristics

NEO survey programs should provide initial physical characterization of discovered objects.

- ▶ Primary characteristics of value include size, reflectivity, and color brightness (1st order mineralogical composition)
- ▶ Need physical nature to evaluate threat and plan response
- ▶ Follow up from ground-based facilities on discovery apparition
- ▶ In situ verification of characterization to provide high confidence

# 3: Investigate the Nature of the Impact Threat (3 of 3)

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## 3.2 Planetary Defense Characterization Missions

NASA's science, exploration, and survey missions aimed at NEOs should include determination of the physical characteristics most directly related to planetary defense.

- ▶ Size, mass, density, porosity, composition, rotation, interior structure, binary, surface morphology, surface properties
- ▶ Exploit synergies to assess nature of carbonaceous “rubble piles” to monolithic nickel-iron NEOs

## 4: Prepare to Respond to Impact Threats (1 of 6)

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To prepare an adequate response to the range of potential impact scenarios, NASA should conduct a focused range of activities, from in-space testing of innovative NEO deflection technologies to providing assistance to those agencies responsible for civil defense and disaster response measures.

# 4: Prepare to Respond to Impact Threats (2 of 6)

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**4.1 Disaster Response** — NASA should work with DHS and other relevant U.S. Government agencies to assign roles and formulate plans for civil defense, such as evacuation of threatened areas, should NEO deflection prove impractical.

- ▶ Plan for likely scenario (tens of meters) with little warning
- ▶ Public communication plan: impact area, effects, probs.
- ▶ Coordination a must:
  - NASA has info,
  - DHS has experience





# 4: Prepare to Respond to Impact Threats (3 of 6)

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## 4.2 Deflection Research Program

In parallel with impact disaster response planning, NASA should perform the necessary research and development to perform an in-space test of a deflection campaign, with the goal of modifying, in a controlled manner, the trajectory of a NEO.

- ▶ R&D followed by actual deflection demo
- ▶ With warning, adequate deflection technologies exist
- ▶ Both powerful impulse & gradual, precise deflections
- ▶ Aggressively pursue international, cooperative demo



# 4: Prepare to Respond to Impact Threats (4 of 6)

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## 4.3 Explosive Technologies

Prudent that NASA should collaborate with DoE and DoD to develop an analytic research program on nuclear explosion technology for NEO deflection.

- ▶ Nuclear explosives are considered a rarely needed and last-resort deflection option
- ▶ Mainly large NEOs, late detection
- ▶ NASA should collaborate and provide needed expertise

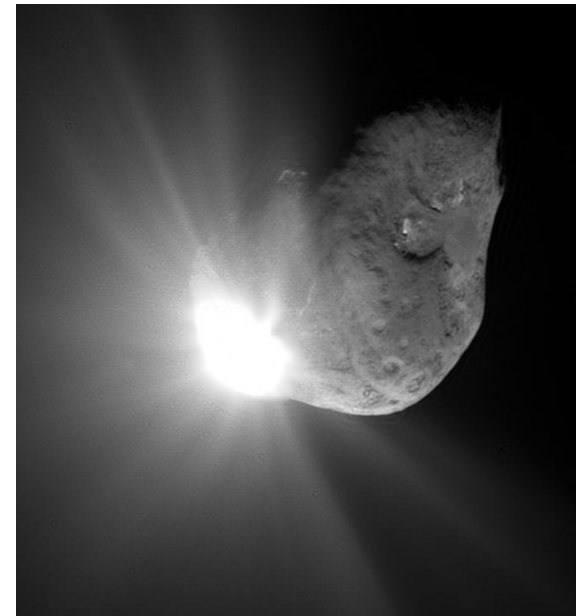
# 4: Prepare to Respond to Impact Threats (5 of 6)

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## 4.4 Deflection Physics

NASA should initiate both analytic and empirical programs to reasonably bound the “momentum multiplier” (termed “ $\beta$ ”) in kinetic impact deflection.

- ▶ Defines projectile momentum transfer augmentation by ejecta
- ▶ Poorly constrained; need analytic and empirical research
- ▶ Hydrocodes, lab gas gun tests
- ▶ Target composition & structure
- ▶ Scaling laws for varied velocities and encounter geometries



# 4: Prepare to Respond to Impact Threats (6 of 6)

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## 4.5 Impact Scenarios

Develop a reference set of a few impact threat scenarios and corresponding deflection campaign design reference missions

- ▶ Shared nationally and internationally, forming the basis for future impact gaming exercises
- ▶ Reinforce “keyhole” considerations
- ▶ Need for periodic monitoring to allow for orbital “fine=tuning”

# 5: Lead U.S. Planetary Defense Efforts in Public and International Forums (1 of 6)

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NASA should provide leadership for the U.S. government to address Planetary Defense issues in interagency, public education, media, and international forums, including conduct of necessary impact research, informing the public of impact threats, working toward an internationally coordinated response, and understanding the societal effects of a potential NEO impact.

# 5: Lead U.S. Planetary Defense Efforts in Public and International Forums (2 of 6)

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## 5.1 Societal Leadership

NASA should lead U.S. government efforts, in public and international forums, to educate, coordinate and act in reducing the threat of a NEO impact.

- ▶ Media
- ▶ Hazards community
- ▶ Military elements for national space and disaster relief
- ▶ Educational institutions for informing citizenry
- ▶ Scientific communities beyond astronomy, for wide-ranging research
- ▶ Space law community
- ▶ Political leaders responsible for effective reactions to unusual societal events

# 5: Lead U.S. Planetary Defense Efforts in Public and International Forums (3 of 6)

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## 5.2 Impact Effects Research

NASA support for research into breadth of physical, environmental, and social consequences of a range of NEO impact scenarios

- ▶ Atmospheric response to large impacts
  - NEO entry
  - Lofting of ejecta
- ▶ Direct impact effects on land (large non-nuclear detonations)
- ▶ Ocean impacts, tsunamis
- ▶ Psychological, sociological effects on a NEO-inexperienced public





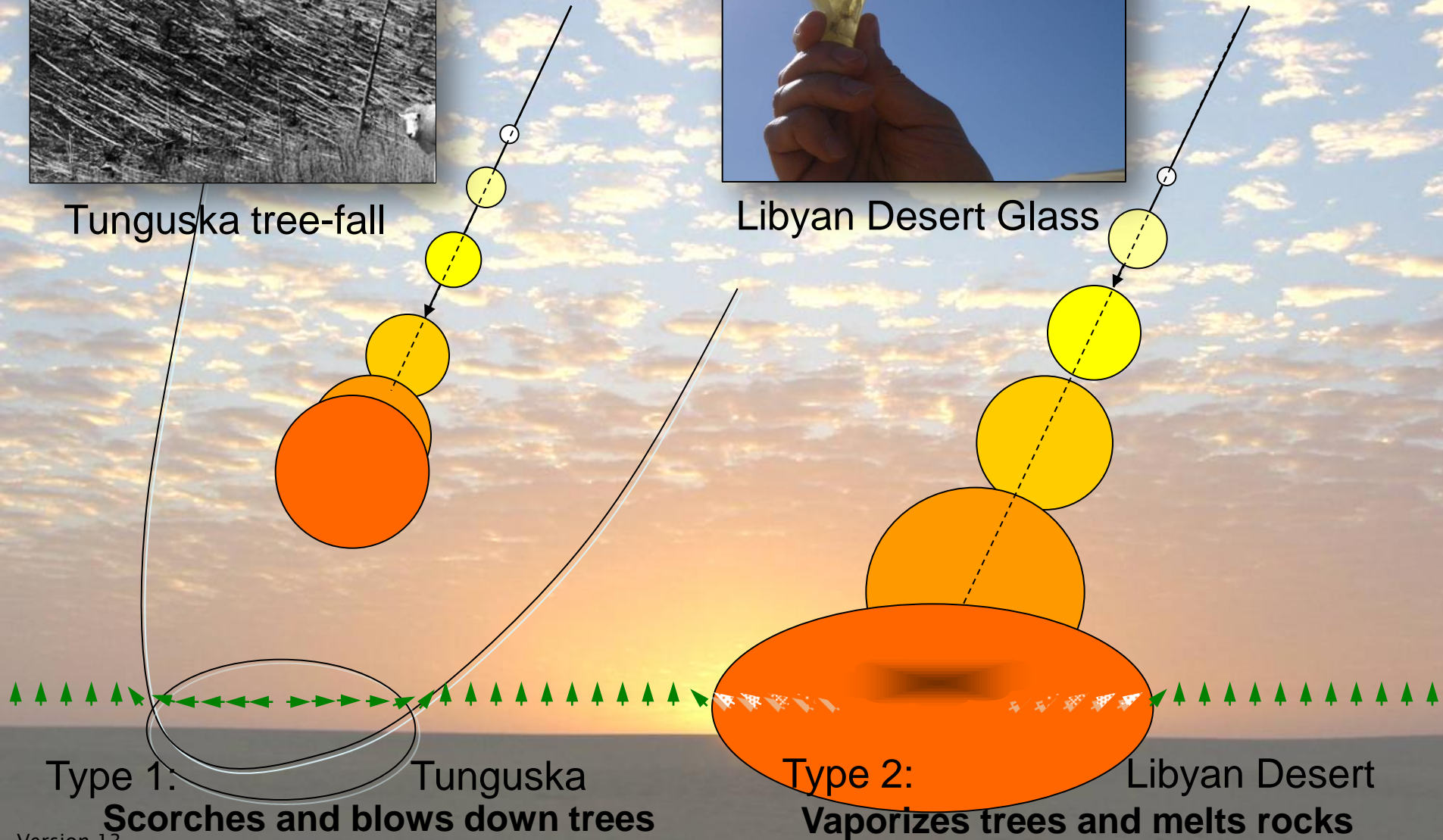
# Two types of Low-Altitude Airburst



Tunguska tree-fall



Libyan Desert Glass





# 5: Lead U.S. Planetary Defense Efforts in Public and International Forums (4 of 6)

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## 5.3 Impact Simulation

NASA and other PD–relevant agencies should develop representative impact threat timelines (linked to reference deflection missions).

- ▶ Initiate periodic multi–agency response simulations and evaluations
- ▶ Extend knowledge to coordinating disaster response agencies
- ▶ Inexpensive table–top exercises for interagency coordination
  - ▶ Using detailed impact scenario timeline
- ▶ A set of such timelines couples to design reference missions

# 5: Lead U.S. Planetary Defense Efforts in Public and International Forums (5 of 6)

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## 5.4 Communications Plan

NASA and other relevant agencies should collaboratively develop a comprehensive Planetary Defense public communications plan

- ▶ Transparent communication across agencies to NEO-uninitiated public

## 5.5 Legal Implications

NASA should utilize both national and international expertise to develop the legal basis for potential actions related to planetary defense.

- ▶ E.g., Liability, impact warning (or failure to warn), orbit alteration, use of nuclear option

# 5: Lead U.S. Planetary Defense Efforts in Public and International Forums (6 of 6)

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## 5.6 Public Education and Outreach

As the warning agency for PD and possessor of most information about NEOs, NASA should establish a public education and outreach program to inform govt. and public about NEO impact hazards and mitigation options.

- ▶ Counter misinformation, misunderstandings, alarmist interpretations

# Conclusions

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- ▶ NASA has strong foundation for understanding NEO hazard and building a long-term capability to counter NEO impact threat
- ▶ NASA has 2 of 3 elements to prevent future damaging impacts: (1) Search, track, warning and (2) deep space ops capability
- ▶ Actual technology demos being studied, part of future missions
- ▶ Missing 3rd element is international readiness; NASA should lead
- ▶ To do so requires NASA to develop practical means of altering NEO orbit
- ▶ W/O search/detection of smaller NEOs; orbit alteration; lead global deflection efforts, U.S. can only evacuate & respond post-impact
- ▶ NASA should begin now to forge its NEO capacities into global example of how to shield against future impact